



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:)
DENYER ET AL.)
)
Serial No. 09/891,134)
)
Confirmation No: 8833)
)
Filing Date: JUNE 25, 2001)
)
For: IMAGE SENSORS WITH MULTIPLE)
INTEGRATION/READ CYCLES)
)

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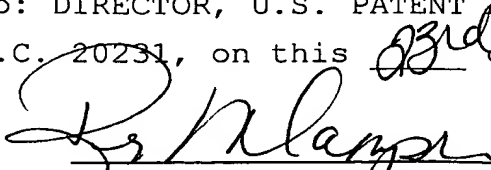
Transmitted herewith is a certified copy of the
priority United Kingdom Application No. 0015685.1.

Respectfully submitted,


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GB0015685.1

By virtue of a direction given under Section 30 of the Patents Act 1977, the application is proceeding in the name of

STMICROELECTRONICS LIMITED

Incorporated in the United Kingdom

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[ADP No. 07460272004]

Request for grant of a patent

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28 JUN 00 E548313-3 002884
1007700 0.00-0015685.1

The Patent Office

Cardiff Road
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South Wales
NP9 1RH

1. Your reference

P26169/TCO/JCO

2. Patent application number

(The Patent Office will fill in this part)

0015685.1

28 JUN 2000

3. Full name, address and postcode of the or of each applicant (underline all surnames)

VLSI Vision Ltd
Vision House
31 PIMLICO
EDINBURGH
EH12 7BF

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

United Kingdom

SECTION 30 (1977 ACT) APPLICATION FILED
077879 300001
16/03/01

4. Title of the invention

"Image Sensors with Multiple Integration/
Read Cycle"

5. Name of your agent (if you have one)

Murgitroyd & Company

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

373 Scotland Street
GLASGOW
G5 8QA

Patents ADP number (if you know it)

1198013

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Country

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7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing
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8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

- a) any applicant named in part 3 is not an inventor, or
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Yes

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Continuation sheets of this form -

Description 13

Claim(s) 3

Abstract -

Drawing(s) 2 + 2

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Priority documents -

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Statement of inventorship and right to grant of a patent (Patents Form 7/77) -

Request for preliminary examination and search (Patents Form 9/77) -

Request for substantive examination (Patents Form 10/77) -

Any other documents (please specify) -

11.

I/We request the grant of a patent on the basis of this application.

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Date

27 June 2000

12. Name and daytime telephone number of person to contact in the United Kingdom

JOHN COOPER

0141 307 8400

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1 Image Sensors with Multiple Integration/Read Cycles

2
3 The present invention relates to solid state image
4 sensors. More particularly, the invention relates to
5 CMOS-type image sensors in which multiple integration
6 and read cycles are performed between resetting of
7 the sensor pixels. This provides the basis for
8 obtaining images which are low in noise and/or having
9 a relatively wide dynamic range and/or which are
10 resistant to flicker induced by mains frequency
11 flickering of artificial light sources.

12
13 Solid state image sensors fabricated using CMOS
14 technology provide a low cost imaging solution, as
15 compared with CCD image sensors, for applications
16 such as digital still cameras, camcorders, web
17 cameras etc. Many kinds of CMOS imaging circuit
18 architectures are possible, including three main
19 types as illustrated in Fig. 1: (a) passive pixel

1 type; (b) 3-transistor active pixel type; and (c) 4-
2 transistor active pixel type.

3

4 A disadvantage of types (a) and (b) above is what is
5 known as "reset noise". This type of noise makes the
6 reset potential of the photodiode forming part of
7 each pixel circuit uncertain, and this uncertainty
8 adds to pixel-to-pixel and frame-to-frame variable
9 noise in both still and video images.

10

11 The rms magnitude of this reset noise is known to be:

12

13
$$N_{rst} = \sqrt{(kT/C)} \text{ volts}$$

14

15 Where k is Boltzmann's constant, T is absolute
16 temperature in Kelvin, and C is the capacitance of
17 the node being reset.

18

19 Pixel type (c) above does not suffer from this type
20 of effect if a special type of buried diode is
21 employed which enables the reset node to be entirely
22 depleted of free charge. Photodiode arrays of this
23 type ("pinned" photodiode arrays) require at least
24 one manufacturing process step in addition to the
25 normal CMOS process, and incur an overhead cost of at
26 least one additional transistor per pixel as compared
27 with a 3-transistor active pixel.

28

29 CMOS image sensors may also suffer a performance
30 disadvantage in environments which are lit by
31 artificial light sources whose intensity varies

1 rapidly in time with the AC mains supply frequency,
2 or at some harmonic of this frequency. For example,
3 fluorescent lights "flicker" at twice the supply the
4 frequency. In these conditions the exposure mode of
5 most un-shuttered CMOS sensors causes horizontal
6 banding interference in the image, which may also be
7 seen to scroll vertically.

8
9 It is known to correct this flicker effect by making
10 the exposure time substantially equal to one period
11 of the flickering source, or an integer multiple
12 thereof.

13
14 A third disadvantage, which is common to most image
15 sensors, is that the range of scene luminances that
16 can be captured in one frame (i.e. the dynamic range
17 of the sensor) is significantly limited. In
18 practice, certain noise mechanisms limit the lowest
19 luminance levels, and combinations of supply voltage
20 and circuit design cause areas of the scene which are
21 above a critical luminance to be clipped or
22 saturated. Typically, the dynamic range available in
23 one frame is limited to about 60 dB, but most real
24 scenes contain luminance ranges greater than this.

25
26 The present invention relates to image sensors having
27 modes of operation in which the operation and timing
28 of certain active pixel sensor arrays substantially
29 eliminates the effects of reset and flicker noise,
30 whilst also expanding the available instantaneous
31 dynamic range.

1
2 The invention may be applied to any active pixel
3 architecture which supports a non-destructive read of
4 pixel values; e.g. type (b) 3-transistor types as
5 discussed above, but not type (a) passive pixels.

6 The invention exploits the fact that, with pixel
7 types which support non-destructive read operations,
8 it becomes possible to perform multiple, staggered
9 read operations without the pixels being re-set
10 between read operations, so that the data read at any
11 particular point in time represents the cumulative
12 signal integrated up to that point since the last
13 time the pixels were re-set.

14
15 The invention is particularly intended for use with
16 CMOS type image sensors, image sensor systems and
17 cameras.

18
19 In accordance with a first aspect of the invention,
20 there is provided a method of operating a solid state
21 image sensor having an image sensing array comprising
22 a plurality of active pixels, the method comprising:

23 resetting each said pixel;

24 after a first predetermined period of time
25 reading a first output from each said pixel so as to
26 obtain a first set of image data having a first
27 dynamic range;

28 without resetting said pixels, after a second
29 predetermined period of time reading a second output
30 from each said pixel so as to obtain a second set of
31 image data having a second dynamic range; and

1 combining said first and second sets of image
2 data in order to obtain a resultant set of image data
3 having a further dynamic range different from said
4 first and second dynamic ranges.

5
6 Preferably, the method further comprises, without
7 resetting said pixels, after at least a third
8 predetermined period of time reading at least a third
9 output from each said pixel so as to obtain a third
10 set of image data having a third dynamic range; and

11 combining at least said first, second and third
12 sets of image data in order to obtain a resultant set
13 of image data having a further dynamic range
14 different from said first, second and third dynamic
15 ranges.

16
17 In accordance with a second aspect of the invention,
18 there is provided a method of operating a solid state
19 image sensor having an image sensing array comprising
20 a plurality of active pixels, the method comprising:

21 resetting and immediately reading a preliminary
22 output from each said pixel;

23 after a first predetermined period of time,
24 reading a first output from each said pixel.

25
26 Preferably, the method further includes the step of
27 determining the difference between said preliminary
28 and first outputs so as to obtain a set of image data
29 substantially free of noise components represented by
30 said preliminary outputs.

31

1 Preferably, the method in accordance with the first
2 aspect of the invention is combined with the method
3 in accordance with the second aspect of the
4 invention, wherein said preliminary outputs of the
5 second aspect are read immediately after performing
6 the resetting step of the first aspect.

7
8 Preferably, the method further includes the step of
9 determining the difference between said preliminary
10 outputs and each of said first, second and any
11 subsequent outputs so as to obtain a plurality of
12 said sets of image data each of which is
13 substantially free of noise components represented by
14 said preliminary outputs.

15
16 Preferably, in each of the aforementioned aspects of
17 the invention, the or each said predetermined time
18 period is selected to be an integer multiple of a
19 predetermined lighting flicker period.

20
21 Preferably, in each of the aforementioned aspects of
22 the invention, said image sensing array remains
23 continuously exposed to incident light while the
24 method is performed.

25
26 In accordance with a further aspect of the invention,
27 there is provided a solid state image sensor adapted
28 to perform a method in accordance with any one of the
29 first to third aspects of the invention.

30 In accordance with another aspect of the invention,
31 there is provided a solid state image sensor system

1 adapted to perform a method in accordance with any
2 one of the first to third aspects of the invention.

3
4 In accordance with still another aspect of the
5 invention, there is provided a camera incorporating a
6 solid state image sensor or image sensor system
7 adapted to perform a method in accordance with any
8 one of the first to third aspects of the invention.

9
10 US-A-5926214 discloses image sensors and methods of
11 operation thereof wherein multiple read cycles are
12 performed between resets of an active pixel sensor
13 array. However, these methods are concerned only
14 with noise reduction and require the use of an
15 optical shutter to mask the array from incident light
16 during an initial reset/read cycle and during
17 subsequent read operations between successive
18 integration periods.

19
20 Embodiments of the invention will now be described,
21 by way of example only, with reference to the
22 accompanying drawings, in which:

23
24 Figs. 1(a), 1(b) and 1(c) illustrate, respectively, a
25 passive type image sensor pixel, a 3-transistor
26 active image sensor pixel and a 4-transistor active
27 image pixel; and

28
29 Fig. 2 illustrates a portion of one example of a 3-
30 transistor active pixel image sensor array.

31

1 Referring now to Fig. 2 of the drawings, a 2x2 pixel
2 portion of a typical active pixel CMOS image sensor
3 array 1 is shown. The array 1 comprises a plurality
4 of rows 3, 5... and columns 4, 6... of active
5 photosensitive pixels 10 defining an image sensing
6 area. The pixels may be addressed sequentially by
7 vertical 12 and horizontal 14 shift registers
8 electronically connected to the pixels as shown, or
9 by any other suitable pixel addressing scheme such as
10 a decoded address scheme. The shift registers 12, 14
11 are electronically connected to scanning circuitry
12 (not shown) for scanning - i.e. reading - the pixel
13 outputs to an output O/P. Any of a variety of
14 known types of active pixel may be used for the
15 pixels of the array. In the array of Fig. 2, the
16 pixels 10 each comprise a photodiode 11 and
17 associated transistor circuitry for use in amplifying
18 (buffering) the diode outputs and for reading and
19 resetting the diodes 11, as is well known in the art.
20

21 In conventional use of a sensor array of this type,
22 the pixels would normally be reset and light would
23 impinge on the photodiodes 11 for a predetermined
24 period (the integration period), before the pixels
25 are read in order to capture a set of image data from
26 the array. The pixels would then be reset prior to
27 each integration period for each image to be
28 captured.
29

1 In accordance with the present invention, multiple
2 reads are performed between successive resets, as
3 follows.

4
5 Firstly, the pixels are reset, destroying any
6 previous pixel signals and forcing the photodiode of
7 each pixel to a known reset voltage (V_{rt}), and are
8 read immediately after being reset (preliminary read
9 cycle or Read 0). It will be understood that, as in
10 conventional image sensor operation, lines (rows or
11 columns) of pixels are reset and read sequentially,
12 so that all of the pixels in one line are reset
13 simultaneously and then read simultaneously.
14 However, this preliminary read cycle is performed
15 immediately after resetting the pixels, rather than
16 after a predetermined integration period as in
17 conventional image sensors.

18
19 The output from each pixel when read immediately
20 after reset is:

21
22
$$Out_0 = V_{rt} + N_{rst} + V_{off} + V_{img}$$

23
24 Where V_{rt} is the reset voltage (described above), N_{rst}
25 is the reset noise (described above and different on
26 each reset occasion), V_{off} is a circuit-induced
27 voltage offset whose value can be unique to each
28 pixel due to local random threshold variations, V_{img}
29 is a signal due to any stray light integration which
30 may have occurred between reset and Read 0. That is,
31 Out_0 comprises a "dark" signal which contains noise

1 comprising the above mentioned components. However,
2 these noise components remain substantially constant
3 over short periods of time and until a new reset
4 occurs.

5
6 Following Read 0, without resetting the pixels, light
7 is integrated during a first predetermined
8 integration period, T_{int1} , producing a signal, Sig_1 ,
9 within each pixel due to the discharge of pixel
10 capacitance by way of photo-induced leakage current.
11 A first read cycle, Read 1, is performed at the end
12 of T_{int1} . The output from each pixel when read at the
13 end of T_{int1} is:

14
15
$$Out_1 = V_{rt} + N_{rst} + V_{off} + V_{img} + Sig_1.$$

16

17 By calculating the difference between Out_0 and Out_1 ,
18 the value of Sig_1 can be determined free of the noise
19 components which comprise Out_0 , since these
20 components are constant between Read 1 and Read 2;
21 i.e.

22
23
$$Out_1 - Out_0 = Sig_1.$$

24

25 The read process described thus far therefore
26 provides an output signal which is substantially free
27 of noise.

28
29 Preferably, at least one further read cycle, Read 2,
30 is performed after a second predetermined integration
31 period, T_{int2} , again without resetting the pixels,

1 resulting in further discharge of the photodiode
2 capacitance and producing a further signal, Sig_2 ,
3 such that

4

$$5 \quad \quad \quad Out_2 - Out_1 = Sig_2;$$

6 and

7

$$8 \quad \quad \quad Out_2 - Out_0 = Sig_3;$$

9

10 Where $Sig_3 = Sig_1 + Sig_2$ and where Sig_2 and Sig_3 are
11 also substantially free of the noise components
12 represented by Out_0 .

13

14 It can be seen that Sig_1 , Sig_2 and Sig_3 provide sets
15 of image data with different exposure periods so that
16 the sensor outputs obtained from the three read
17 cycles provide three different representations of the
18 same scene taken close together in time and having
19 different dynamic ranges. Sig_1 , corresponding to the
20 shortest integration period, will contain most
21 information from relatively bright image areas but is
22 likely to be underexposed in relatively dim image
23 areas, Sig_2 will provide an intermediate view and
24 Sig_3 will contain most information from relatively
25 dim image areas but is likely to be overexposed in
26 relatively bright image areas. The three images may
27 then be combined in order to obtain a composite image
28 having a dynamic range wider than could be obtained
29 by means of a single integration period.

30

1 The three images may be combined in any of a variety
2 of ways. Generally speaking, the signals will be
3 normalised so that the highest luminance values from
4 the first (shortest exposure) image are scaled to the
5 upper end of a predetermined range of output values,
6 the lowest luminance values from the third (longest
7 exposure) image are scaled to the lower end of the
8 range of output values, and intermediate composite
9 output values are determined by combining and/or
10 scaling intermediate values from all three images.

11
12 The pixels may be reset following the final read
13 cycle. It will be understood that the number of read
14 cycles may vary between resets. The method may be
15 implemented using a substantially conventional image
16 sensor, with suitably adapted control software and/or
17 firmware and/or hardware for controlling the timing
18 of reset and read cycles, sufficient frame storage
19 resources to store the multiple sets of data captured
20 in each read cycle, and suitable image processing
21 software and/or firmware and/or hardware for
22 combining the image data as required. Obviously, the
23 greater the number of read cycles the greater the
24 overhead of frame storage and data processing.

25
26 It will be understood that the increased dynamic
27 range obtained by means of multiple integration
28 periods and read cycles may be usefully employed
29 independently of the preliminary read cycle (Read 0)
30 which allows the cancellation of noise from the
31 images. However, it is preferred that these

1 operations are combined in order to obtain images
2 having low noise and wide dynamic range.

3

4 All of the images obtained by means of such multiple
5 read cycles may be free of lighting flicker effects
6 if the integration periods are each selected to be
7 integer multiples of any lighting flicker period.

8

9 It will also be understood that the methods and image
10 sensors of the present invention do not require the
11 use of an optical shutter in order to mask the image
12 sensor either during the initial reset/read operation
13 or during subsequent read operations. Read 0 is
14 performed immediately after reset, with resetting and
15 reading being performed on a sequential, line-by-line
16 basis, and subsequent reads are performed in a
17 similar manner while integration continues.

18

19 The methods of the invention may be implemented by
20 means of a suitably adapted image sensor, or image
21 sensor system, or camera incorporating an image
22 sensor or image sensor system. The methods are also
23 applicable to any type of active pixel architecture,
24 most suitably of the CMOS type, supporting non-
25 destructive read operations. Additional examples of
26 such pixel architectures are illustrated in US-A-
27 5926214.

28

29 Improvements and modifications may be incorporated
30 without departing from the scope of the invention as
31 defined in the Claims appended hereto.

1 Claims

2
3 1. A method of operating a solid state image sensor
4 having an image sensing array comprising a plurality
5 of active pixels, the method comprising:

6 resetting each said pixel;

7 after a first predetermined period of time
8 reading a first output from each said pixel so as to
9 obtain a first set of image data having a first
10 dynamic range;

11 without resetting said pixels, after a second
12 predetermined period of time reading a second output
13 from each said pixel so as to obtain a second set of
14 image data having a second dynamic range; and

15 combining said first and second sets of image
16 data in order to obtain a resultant set of image data
17 having a further dynamic range different from said
18 first and second dynamic ranges.

19
20 2. A method as claimed in Claim 1, further
21 comprising, without resetting said pixels, after at
22 least a third predetermined period of time reading at
23 least a third output from each said pixel so as to
24 obtain a third set of image data having a third
25 dynamic range; and

26 combining at least said first, second and third
27 sets of image data in order to obtain a resultant set
28 of image data having a further dynamic range
29 different from said first, second and third dynamic
30 ranges.

31

1
2 3. A method of operating a solid state image sensor
3 having an image sensing array comprising a plurality
4 of active pixels, the method comprising:

5 resetting and immediately reading a preliminary
6 output from each said pixel;

7 after a first predetermined period of time,
8 reading a first output from each said pixel.

9
10 4. A method as claimed in Claim 3, further
11 including the step of determining the difference
12 between said preliminary and first outputs so as to
13 obtain a set of image data substantially free of
14 noise components represented by said preliminary
15 outputs.

16
17 5. A method as claimed in Claim 1 or Claim 2, in
18 combination with a method as claimed in Claim 3 or
19 Claim 4, wherein said preliminary outputs of Claim 3
20 or Claim 4 are read immediately after performing the
21 resetting step of Claim 1 or Claim 2.

22
23 6. A method as claimed in Claim 5, further
24 including the step of determining the difference
25 between said preliminary outputs and each of said
26 first, second and any subsequent outputs so as to
27 obtain a plurality of said sets of image data each of
28 which is substantially free of noise components
29 represented by said preliminary outputs.
30

1 7. A method as claimed in any preceding Claim,
2 wherein the or each said predetermined time period is
3 selected to be an integer multiple of a predetermined
4 lighting flicker period.

5

6 8. A method as claimed in any preceding Claim,
7 wherein said image sensing array remains continuously
8 exposed to incident light while the method is
9 performed.

10

11 9. A solid state image sensor adapted to perform a
12 method as claimed in any one of Claims 1 to 8.

13

14 10. A solid state image sensor system adapted to
15 perform a method as claimed in any one of Claims 1 to
16 8.

17

18 11. A camera incorporating a solid state image
19 sensor or image sensor system adapted to perform a
20 method as claimed in any one of Claims 1 to 8.

21

22

23

24

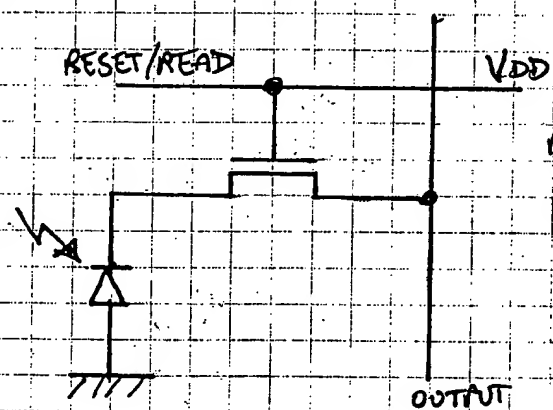


FIG. 1(a)

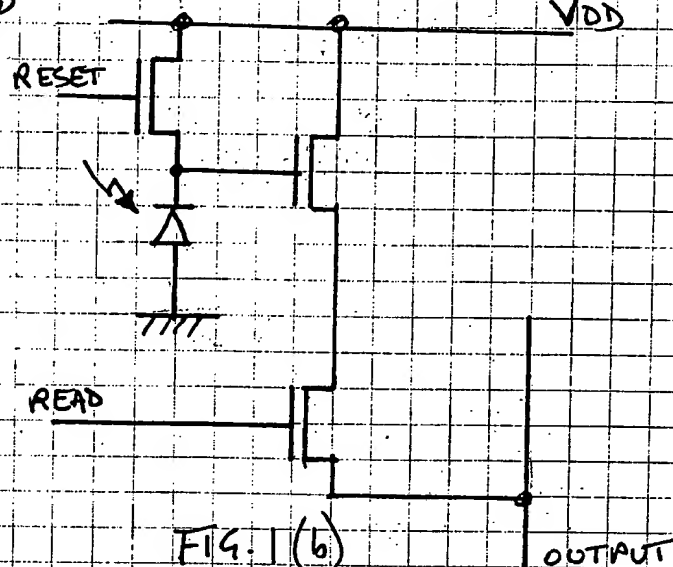


FIG. 1(b)

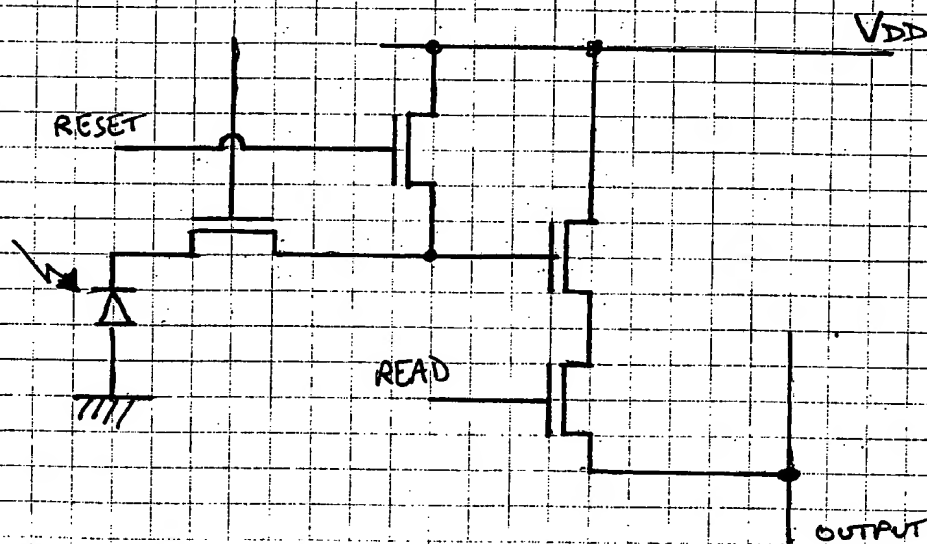


FIG. 1(c)

